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A Quality Control Case Study of Kitchen Appliance Production: An Engineering Case for Graduate Education

Sourabh P. Choudhari
Iowa State University

A Quality Control Case Study of Kitchen Appliance Production: An Engineering Case for Graduate Education

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Sourabh P. Choudhari

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Gary Mirka

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this creative component. The Graduate College will ensure this creative component is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I dedicate this creative component to my parents Mrs. Vaishali and Mr. Prakash Choudhari, and my brother Mr. Chetan Choudhari for their unconditional love and support.

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ABSTRACT

This case study presents CoolKast, a leading household appliance company, which focuses on problems in the assembly line of new refrigerators. The refrigerator plant keeps a record of all the quality problems reported within the organization and its customers.

Part A of the case study concentrates on current issues that involve a lack of attention to quality, inadequate production planning, and a failure to communicate and engage with employees. Quality procedures for past products and new products on the line are discussed in detail. There are concerns regarding the cost and improving the quality of the production processes. The quality control, process, and maintenance teams should address the underlying problems in the assembly and manufacturing of the refrigerators, especially with respect to the process of inserting foam into the refrigerators.

Part B of the case study presents data on the foaming process for the refrigerators in order to identify areas and evaluate root causes in the foaming process for these refrigerators.

CHAPTER 1: INTRODUCTION

Statistical process control (SPC) can be applied to a vast number of applications in health care, manufacturing, and in other fields and industries where data is generated or material is produced without any kind of interruption. It is used to control the conditions ensuring better quality and efficient system. The greatest obstacle in the use of SPC is the lack of training. Many organizations tend to rely on inspection-based quality procedures in place of process control procedures, which affect the quality of the products in the long run.

This case is about CoolKast, a major household appliance company that introduced a range of new refrigerators running on assembly line 44 at the Milford facility. The case study is a two-part case focusing on qualitative and quantitative aspects of production processes, useful in quality control.

The case study is designed for the IE-561 Total Quality Management course and is an application of statistical process control analysis. My engineering co-op experience helped me set up the problem statement for the case study. Based on some real and hypothetical situations, the case study describes the problems some manufacturing organizations face from management level to employee level and their impact on product quality. It incorporates management level decisions, quality control procedures at the production facility, and the impact of choosing alternatives. It also demonstrates how some of Dr. Edwards Deming’s lessons about quality could help to make decisions and resolve problems in this case.

CHAPTER 2: CASE STUDY

PART A: IMPROVING PROCESS QUALITY

2.1 Company Background

CoolKast, a Fortune 500 company with annual revenue of $10 billion, has been the world's leading household appliance company for several decades and had recently focused on expanding its business through the North America region. CoolKast's products include cooktops, dishwashers, microwaves, refrigerators, water coolers, washing machines, and dryers. Two decades ago, the company acquired KitchenWire based in Milford city and began producing refrigerators that revolutionized the kitchen appliance industry. The refrigerator division at Milford accounts for approximately 40% of the company's revenue.

Last year CoolKast recorded a decline in sales of 5% in North America, much of it due to declining sales in the company's refrigerator division. CoolKast executives are exploring what the Milford plant can do better to turn sales around in its refrigerator division. Successful leadership and management of the quality department for an organization involve a communication network that extends to the organization, its customers, and the suppliers. The Milford plant keeps a record of all the quality problems reported within the organization and from the customers. Customers are complaining about improper cooling, refrigerator cabinets heating, and high energy consumption. Organization-based problems seem to involve a lack of attention to quality, inadequate production planning, and a failure to communicate and engage with employees. Management needs to determine the root causes of quality problems in refrigerators produced by the Milford plant so that production schedules can return to what they were before the slowdown.

2.2 Refrigerator production at Milford

The refrigerator production unit at Milford is divided into two sections: fabrication and assembly. In the fabrication section, a thin metallic sheet is cut and bent into the desired shape. The cabinet is sent to the assembly line area to install components like LEDs, plastic liners, shelves, electrical circuits, copper coils, compressor and condenser coils, and doors. The assembly section is divided into three areas. Each assembly area performs different tests to check for the quality and performance of the different parts. After all the components are installed and tested, the refrigerator cabinets are sent to the packaging area. They are packed and stored in containers ready to be delivered to the market.

Milford has four production lines (lines 33, 44, 65, and 70). Assembly line 44 produces the most complicated refrigerators for CoolKast. Line 44 produces a premium range of refrigerators in the consumer market. Three years ago, after carefully beta testing new products and receiving feedback from the beta testers, the company introduced a range of new products on line 44 that are 30% more energy-efficient and had 20% more storage space:

- Magna: a 37-inch wide French door refrigerator
- Amber: a 37-inch wide double drawer French door refrigerator
- Meadow: a 34-inch wide 4-door French door refrigerator

The introduction of new products meant changes to the already existing assembly line. Optimize the existing standard operating procedures at each station, supply new and modified parts, maintain the right inventory levels, changes to the robots and automatic processes, and design a new marketing plan. For the line of new products, Line 44 was equipped with new collaborative robots or COBOTS, and conveyors, lifts, and padding to reduce direct contact with sharp surfaces. Bill Schultz, the Director of Operations, is responsible for managing operations at line 44 and supervising this range of new products.

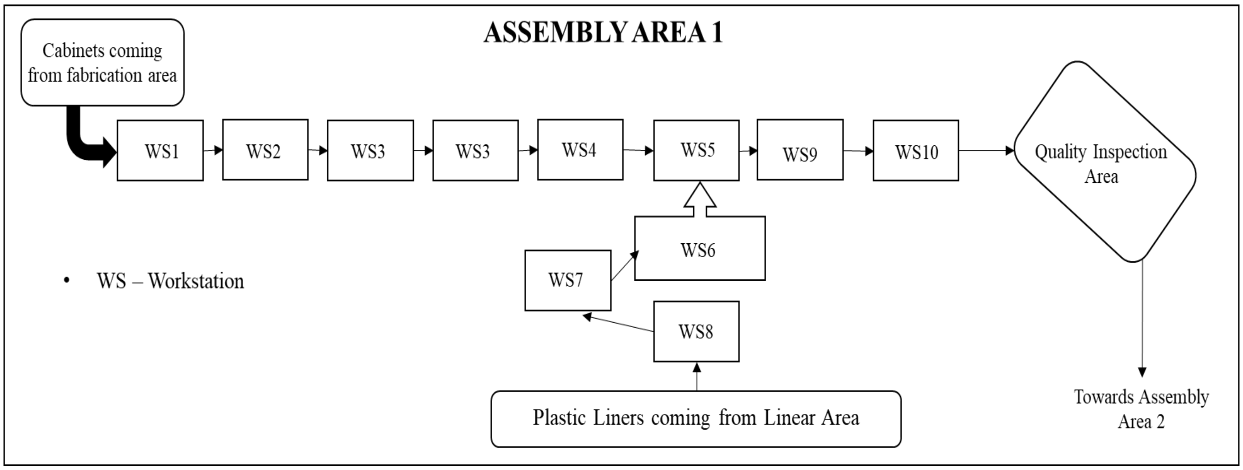

Figure 1: Assembly area 1 sample layout

Assembly area 1 contains 12 stations. Empty refrigerator cabinets enter the assembly line, and operators install parts like caster wheels, high-voltage (HV) box wire harnesses, LEDs, plastic liners, vacuum panels, shelves, copper tubes, and door hinges at different stations. A quality inspector inspects the cabinets for any missing or excess parts at the end of the assembly area. The most common defects in this area are missing screws, damaged vacuum panels, broken wires from HV boxes, faulty LEDs, cracked liners, and bent and misaligned copper tubes.

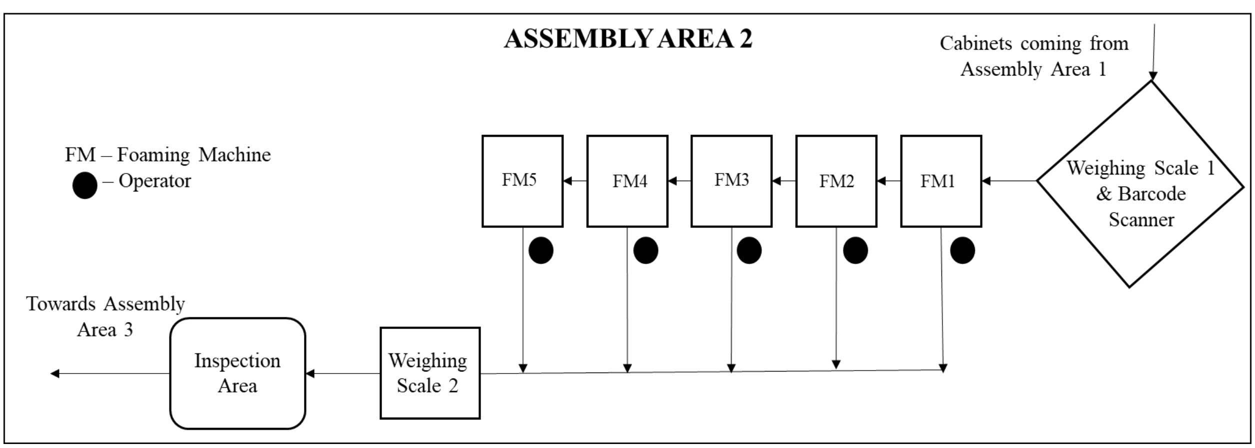

Figure 2: Assembly area 2 sample layout

Assembly area 2 consists of 13 working stations performing different operations. At the start of assembly area 2, the cabinets are weighed after being received from assembly area 1. Polyurethane foam is filled in the cabinet in a controlled temperature and pressure setting. After the foaming process, the working stations install components such as condenser coils, compressors, refrigerants, and a silicone-based adhesive gel to seal the edges of the cabinet. Copper tubes are brazed to the compressors. At the end of the assembly area, the cabinets are checked for any defects. The foaming process and brazing process are critical quality factors. The most common defects are less or excess foam in the cabinet, less refrigerant in the compressors, and foam coming out on the edges of the cabinet, which indicates improper sealing.

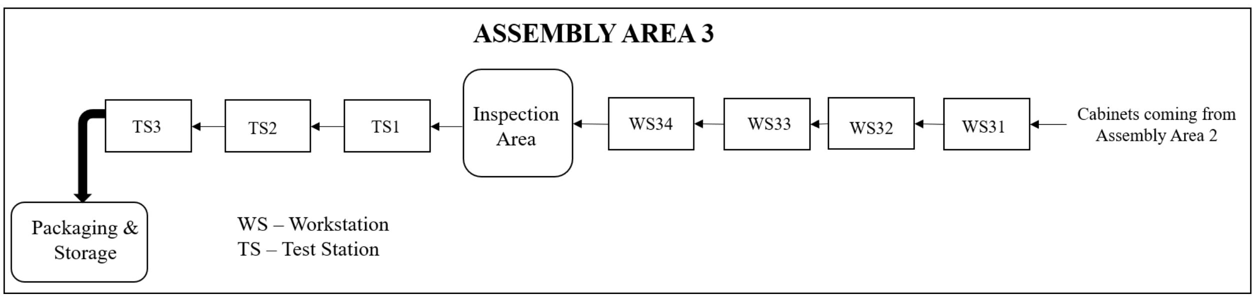

Figure 3: Assembly area 3 sample layout

Assembly area 3 has ten working stations. In this assembly area, all the doors, shelves, and pantry drawers are installed. At the end of the assembly area, the cabinet goes through the end of line (EOL) testing. The EOL testing consists of tests on the icemaker to check if an adequate amount of cooling is supplied to the icemaker, tests on the power door to ensure that all the electronic buttons on the power door are working, proper alignment of doors and drawers, and rechecking the physical attributes for defects. After passing all the tests, the cabinet is sent to the packaging area, packed and ready to be shipped.

2.3 Quality procedures at line 44

Line 44 runs two shifts per day, and a single shift produces around 150 to 175 cabinets daily. The quality control (QC) team is responsible for all quality-related issues on line 44. At each stage of the assembly areas, quality inspectors inspect the refrigerator cabinets for any defects. The QC team uses different tools and gauges to verify defects. The team also uses visual criteria to check for any physical defects present on all the cabinets' sides.

Jim Reyes, the quality engineer for line 44, is studying and analyzing the current sampling strategy. The QC inspectors randomly sample 15 out every 50 cabinets run on the line in assembly areas 1 and 3. They randomly sample 20 out every 50 cabinets at the end of assembly area 2. If a cabinet contains defects or measurements exceed the allowable limits, the lot is held, and the root cause of the defects is identified and fixed. If the root cause is difficult to identify or fix, the QC team takes the lot out of the assembly line and critically inspects each cabinet. This results in downtime for the entire line and reduces each assembly area's yield and line 44. It would be prohibitively expensive for CoolKast to significantly increase the cabinet's sampling to achieve a significant level of confidence that only non-defective cabinets would be shipped.

2.4 Quality problems at assembly area 2

Customer service representatives are receiving several calls with complaints that the new refrigerator models are not cooling correctly, having too much condensation, consuming too much power, and overheating on the sides. The QC team suspects these problems are related to the foaming process in assembly area 2. Customer service representatives have not been capturing the specific refrigerator serial number.

Assembly area 2 experienced issues related to downtime and physical and functional defects before the new refrigerator models were introduced three years ago. The conveyor systems on that line were unable to handle the daily production and frequently broke down. Many cabinets got scratched or dented, resulting in the scrapping of the cabinets and the parts installed in the cabinets.

A new and better conveyor system was installed when the new models were introduced. The problems related to older models were reduced but not entirely resolved, and line 44 faced a new set of challenges. The assembly line layout was changed to match the production needs of the new products. Standard operating procedures were either changed or newly developed for each workstation. The number of operators working in assembly area 2 increased from 35 to 50. All the operators were trained for six weeks for the new system of operation. As most of the operators had experience working on older models, some have found it easier to adapt to the new operating procedures. Others have been reluctant to adapt to the new system. Operator availability was also subject to weather conditions.

The QC team in assembly area 2 has 15 inspectors responsible for sampling the cabinets as fast as possible and all day long. The cost of scrap from assembly area 2 due to the QC team finding defects is about $750,000 per year. Moreover, cabinets would be inspected at each assembly area and scrapped from each lot. Bill Schultz asked Reyes and Caroline Stokes, the process engineering team leader, to head up a team for investigation ways to reduce quality monitoring costs while maintaining or improving product quality.

2.5 Problems in the foaming process

The foaming machines were installed in the early 2000s and were specifically designed for the older models. The new models were designed based on these foaming machines so that CoolKast would not need to buy new foaming machines. A set of foaming machines could cost the company $60,000-$70,000 per set, and the assembly line houses five foaming machines.

CoolKast decided to avoid the costs for new foaming machines and use the money for new product development.

Process engineers are responsible for gathering data and performing analyses of the foaming process. These engineers track the temperature, pressure, and the size and time of the foam shot size. The process engineers began measuring and analyzing established key performance indicators and process characteristics. Manufacturing and mechanical engineers are responsible for periodic maintenance and the proper functioning of the foaming machines. The QC team, process engineers, and maintenance teams are assigned specific areas to monitor to identify problems for line 44.

The operators are responsible for calibrating the foaming machines daily for each model, and each model requires different shot sizes and shot timings. The operators are free to change the temperature, pressure, and other settings on the foaming machines. The temperature and pressure required to release the foam also need to be calibrated. For example, the Magna cabinets need to be sprayed with foam for 4.2 seconds, and the Meadow and Amber cabinets require 4.41 seconds of a foam shot. If the operator forgets to calibrate the foaming machine before changing to a new model, the model on the line would be installed with the wrong foam size quantity. This would result in scrapping those cabinets.

Table 1: Calibration settings required for each model during the foaming process

Model	**Foaming machine**		**Ambient**		**Shot time**
	Temperature (°F)	**Pressure (lbs/in^2)**	**Temperature (°F)**	**Pressure (lbs/in^2)**	
Magna	60-80	1900	60-80	2000	4.2 sec
Amber	60-80	1920	60-80	2000	4.41 sec
Meadow	60-80	1900	60-80	2000	4.41 sec

The ambient temperature and pressure conditions also affect the shot size and shot timing. Polyurethane rigid foam is the insulating material that is widely used throughout the world for refrigerators and freezers. The insulation efficiency of polyurethane foam is a crucial property for refrigerators and freezers to maintain the ability to preserve food at low temperatures during processing, storage, and distribution to the consumer. The foam reacts to changes in the surrounding temperature and pressure conditions. The Milford facility's operating temperatures usually vary between 70°F to 90°F but can go up to 130°F during the summer.

Similarly, the pressure conditions vary for each model. The varying temperature and pressures affect the shot timings. The foam reacts to increasing temperature, which means that the foam shot timing needs to be recalibrated. The timing should be less if temperatures are higher. Operators may need to recalibrate the foaming machine's mid-operation only if the temperatures remain elevated.

Excess foam can leak out around the edges of the refrigerator cabinets. The cabinets with leaking edges are cleaned. Cleaning cabinets sometimes damage the cabinets. A weighing scale measures the cabinet weight at the end of the foaming process. Overweight cabinets are sometimes allowed to pass through the inspection area if no other defects are found.

Reyes, the quality engineer for line 44, speculated that the foam expanded with irregular gaps and cavities. He believed that the polyurethane foam's chemical composition was not correct and resulted in gaps and cavities. The process engineers tested the foam in the chemical lab and found that the chemical components were not appropriately mixed, which generated a different density profile of foam after expansion.

QUESTIONS: PART A

1. What do you think are underlying issues leading to quality problems with the new refrigerator cabinets?
2. What would be key elements in a plan to improve CoolKast's quality procedures for line 44?
3. What should be the next steps for the process engineers to help resolve problems with the foaming process?
4. Where do you think Dr. Deming's principles could be applied to help CoolKast improve its quality procedures?

PART B: STATISTICAL PROCESS CONTROL

Reyes and his team determined that they need to switch from sampling and inspection to a system that relies on data standardization and the best manufacturing practices. The quality control team set up a new system in assembly area 2 to measure the pre-foam and post-foam weight of the refrigerator cabinets and the temperature and pressure conditions within and outside the machines. Assembly area 2 machine operators were free to change the shot size based on the foaming machines' temperature and pressure.

The Excel file FoamMachine.xlsx contains the data from a week of measuring the pre-foam and post-foam weight of the refrigerator cabinets. The weight of the foam, calculated as the difference between the post-foam and pre-foam weight of the cabinet, is the response variable. Six possible factors are recorded to assess the impact on the weight of the foam.

1. Day of the week: 1, 2, 3, 4, 5 (ordinal variable)
2. Shift during the day: 1, 2 (ordinal variable)
3. Type of refrigerator model: Amber, Meadow, Magna (nominal variable)
4. Foaming machine: 1, 2, 3, 4, 5 (nominal variable)
5. Pressure of the foaming machine: real variable
6. Temperature of the foaming machine: real variable
7. Weight of the foam: real variable

The specifications for the weight of the foam is based on the mean of the foam weight that is assessed from the weeks' worth of data. Based on their experience, the production team believes that having excess foam is less problematic than having too little foam. Consequently, the lower specification limit (LSL) is defined as 98% of the calculated mean of the foam weight, and the upper specification limit (USL) is defined as 105% of the calculated mean. For example, if the mean foam weight is 10 kg, the LSL is 9.8 kg, and the USL is 10.5 kg. The production team believes that the quality of the refrigerator cabinets will be enhanced significantly if the foaming process can ensure that the foam weight exceeds 98% of the mean foam weight. A defect in the foaming process occurs if the foam weight exceeds the USL or is less than the LSL.

The quality control plans to analyze the data collected over the week using three different methods. First, the number of defects that correspond to each of the nominal or ordinal variables is assessed to understand if any one factor seems important in leading to defects in the foaming process. Second, separate control charts are created for each day to examine trends in the data and when the most defects occur. The control charts are created with the LSL and USL, as well as with lower control limits and upper control limits based on the data for each day.

Finally, multiple factors could be contributing individually or in combination to produce defects in the foaming process. The team plans to do a multi-factor analysis of variance (ANOVA) with all six variables as main effects and two-way interactions between each of the seven main effects. This ANOVA should provide guidance on which factors most significantly impact the foam weight, especially the factors that generate too little foam. The quality control team will investigate these factors more extensively to identify root causes.

Use the data in the Excel file to pursue each of the three methods the quality control team intends to pursue.

QUESTIONS: PART B

1. Which nominal or ordinal variable (day, shift, model, or foaming machine) seems to have a significant impact on the number of defects in the foaming process? Based on the results of the first method, where would you suggest further investigation should occur?
2. Construct and analyze the appropriate quality control charts for each day, first with specified mean and limits, and then with the calculated mean and control limits. What conclusions can you draw from this analysis?
3. From your analysis of the foam weight, is the process in control?
4. Carry out a multi-factor ANOVA for the foam weights. What factors contribute to the variation in foam weights?
5. What recommendations would you make to the quality control team for the next steps to address issues in the foaming process?

CHAPTER 3: TEACHING NOTES

3.1 Synopsis

This case study presents CoolKast, a leading household appliance company, which focuses on problems in the assembly line of a new refrigerator. The refrigerator plant keeps a record of all the quality problems reported within the organization and its customers. Part A of the case study concentrates on current issues that involve a lack of attention to quality, inadequate production planning, and a failure to communicate and engage with employees. Quality procedures for past products and new products on the line are discussed in detail. There are concerns regarding the cost and improving the quality of the production processes. The quality control, process, and maintenance teams should address the underlying problems in the assembly and manufacturing of the refrigerators, especially with respect to the process of inserting foam into the refrigerators. Part B of the case study presents data on the foaming process for the refrigerators, and three methods are used to identify and evaluate root causes in the foaming process for these refrigerators.

3.2 Target learning group

This case is targeted for graduate students in industrial or mechanical engineering or business. The case is appropriate for courses in quality, management, and risk management. Questions for discussion in Part B assume knowledge in statistical quality control (e.g., control charts and ANOVA analysis). Results from these models could be presented and discussed without knowing how to build the models.

3.3 Learning objectives and key issues

The CoolKast case study illustrates issues that most manufacturing organizations face if established processes are neither predictable nor reliable. Students discover how to approach a problem, where to begin, and what sequence of steps to follow for process control. After completion of the lesson's, students will be able to:

1. Identify and resolve key organizational problems that can impact quality in manufacturing.
2. Create an action plan to execute the next steps in process improvement.
3. Describe how processes can save money but could lead to inferior quality products.
4. Analyze and interpret data using control charts, evaluate possible trends, and determine factors leading to an out-of-control process.
5. Evaluate the individual and combined effect of the variables on the process by running a multi-factor ANOVA.

3.4 Teaching strategy

The purpose of this case study is to allow students to discover methods for improving non-standardized operations or in-control processes. Part A talks about the processes and current issues in the plant. Part B talks about statistical process control analysis using three different methods. Part B consists of specification limits and control limits. The specification limits are set up based on historical data and experience. First, the data collected for the week will be analyzed to see if any factor is causing maximum defects for each variable. Second, separate control charts using specification limits and control limits will be analyzed to see any trends, natural or special causes leading to defects in the foaming process. Finally, the contribution of multiple factors is assessed by doing a multi-factor analysis of variance (ANOVA). The first ANOVA will reveal some significant main effects and two-way interactions. A second ANOVA using the significant variables and interactions from the first run will indicate factors most significantly impacting the foam weight. Part B of the case study could be taught in at least two ways. First, the instructor could provide the control charts and ANOVA table for the students, and students will interpret the results. Second, the instructor could require the students to construct the control charts, perform ANOVA, and interpret the results.

3.5 Part A

Part A focuses on the qualitative aspects of quality control. CoolKast recorded a decline in sales primarily due to the refrigerator plant division. Management is looking for areas that can improve the overall production processes and quality of the refrigerators to increase company sales. Customers are reporting issues related to improper cooling, refrigerator cabinets heating, and high energy consumption. The management is also considering changing its sampling strategy but increasing the number of inspections and samples is prohibitively expensive. The primary area of interest is assembly area 2, where the management believes the issues are arising. Some of the quality issues are carried forward to the new models from the older models, as most of the current quality procedures are updated from the old range of refrigerators. The scrap costs are high, and teams investigate ways to reduce the costs. Foaming machines require constant monitoring and calibration throughout their operation during both shifts. Engineers examine the foaming process to identify areas for improvement. Process engineers will examine the data. Mechanical and manufacturing engineers are responsible for the maintenance of the machine. The discussions in part A should help students understand that on-going issues must be addressed by creating an action plan for improving product quality.

3.6 Questions for discussion

Part A focuses on learning objectives 1, 2 and 3. Table 2 maps each question in part A to one of the three learning objectives.

Table 2: Learning objectives matrix for part A questions

Learning Objectives \ Questions	1	2	3	4
1	•			
2		•	•	
3	•			•

1. What do you think are the underlying issues leading to quality problems with the new refrigerator cabinets?

The line was facing issues related to downtime and physical and functional defects resulting in increased scrap. Issues related to improper cooling, condensation, increased power consumption and overheating. There also seems to be a lack of communication between the management and the operations about the processes with new cabinets resulting in several physical and functional defects. The old foaming machines were in operation to avoid costs but could have resulted in defective cabinets with less or excess foam.

2. What would be key elements in a plan to improve CoolKast's quality procedures for line 44?
    a. The short-term plan by Jim Reyes should be to use quality tools to expose root causes as the current state lacks clarity about the source of problems. Time studies, 5 Whys, and statistical process control analysis can help determine the root causes affecting the production process and implement procedures for operators to fix machines when they are out of control.
    b. Improving communication between the management and operators by addressing concerns and suggesting improvements.

c. Retraining, evaluating, and follow-up of standardized work and reduce abnormal variation by examining the process data.

3. What should be the next steps for the process engineers to help resolve problems with the foaming process?

The process engineers should look for ways to introduce polyurethane foam of constant chemical composition. The team should also look for ways to bring the foaming machines to basic operating conditions without constantly monitoring or tweaking them. Steps should be taken to eliminate or replace the foaming machine if any machines are operating outside their working limits for a prolonged time after maintenance. The team should also perform analyses related to variation to look for areas of improvement.

4. Where do you think Dr. Deming's principles could be applied to help CoolKast improve its quality procedures?

Several of Dr. Edward Deming's points apply to this case. Some of the points that could be applied to improve the quality of the refrigerator cabinets are as follows:

a. Cease dependence on inspection to achieve quality – The management heavily relied on the inspection processes without building quality in the processes itself.
b. End the practice of awarding business based on the price tag – CoolKast seems to have made several decisions based on choosing the low-cost options by keeping some old and outdated systems in processes.
c. Institute training on the job – Most of the operators were trained for the old processes. Retraining on the job may help in improving the processes.

d. Institute leadership – Allow operators to take ownership of processes.

e. Break down barriers – Effective communication between the management and shop floor.

f. Put everybody in the company to work to accomplish the transformation.

Table 3 provides answers to assess the performance of students. Best answer column provides solutions that explains all the points asked in the questions. Satisfactory answer column provides solutions where some parts of the question are answered. Unsatisfactory answer column provides solutions where no parts of the question are answered.

Table 3: Rubrics for answers part A

Question	Best answer	Satisfactory answer	Unsatisfactory answer
1	Physical and functional defects Condensation, improper cooling Lack of communication	Functional defects Increase in scrap Defective cabinets Customer complaints	Inspection procedure Inadequate training
2	Use Quality tools like process control analysis, 5Whys Improve employee communication Train, evaluate standard work, reduce variation	Identify root causes Review customer complaints	Question operators about inconsistencies in the process Reduce inspection activities
3	Constant chemical composition of the foam Bring foaming machines to basic operating conditions Monitor and maintenance of machines	Identify root causes Evaluate the foaming process	Buy new machines Scrap cabinets
4	Many of Dr. Deming’s 14 points apply in CoolKast’s situation	Only 1 or 2 of Dr. Deming's points are identified	There is no explanation of how the principle applies directly to CoolKast

3.7 Part B

Part B focuses on the quantitative aspect of the case study. In this part, the QC team reviews and analyzes the post foam data for the refrigerator cabinets. The team has set lower specification limits for the foam weight as 98% of the mean and upper specification limits as 105% of the mean of the foam weight. Having less foam is considered problematic based on the experience and historical data of the foaming process. The data collected over a week is assessed using three different methods. The teams assess the total number of defects every day of the week to see if any of the nominal or variable factors lead to defects in the process. To examine the trends, the teams assess the data by creating separate control charts with specification limits and lower and upper control limits. Finally, multi-factor ANOVA is performed on the nominal and ordinal variables to see the effect of all six variables as main effects and two-way interactions between each of the six main effects. The results from ANOVA should signify the impact of the variables on the foaming process to identify the root causes.

3.8 Questions for discussion

Part B focuses on learning objectives 2, 4 and 5. Table 4 maps each question in part B to one of the three learning objectives.

Table 4: Learning objectives matrix for part B questions

Learning Objectives \ Questions	1	2	3	4	5
2					•
4	•	•	•		•
5				•	•

1. Which nominal or ordinal variable (day, shift, model, or foaming machine) seems to have a significant impact on the number of defects in the foaming process? Based on the results of the first method, where would you suggest further investigation should occur?

The results indicate that a large number of defects occurred on day 5. Shift 2 has almost two times the defects compared to shift 1. The Magna and Meadow models should also be investigated as the total number of defects is very high compared to Amber. Foaming machine 4 also has a large number of defective cabinets. These variables causing the defects should be investigated in detail to evaluate the root causes.

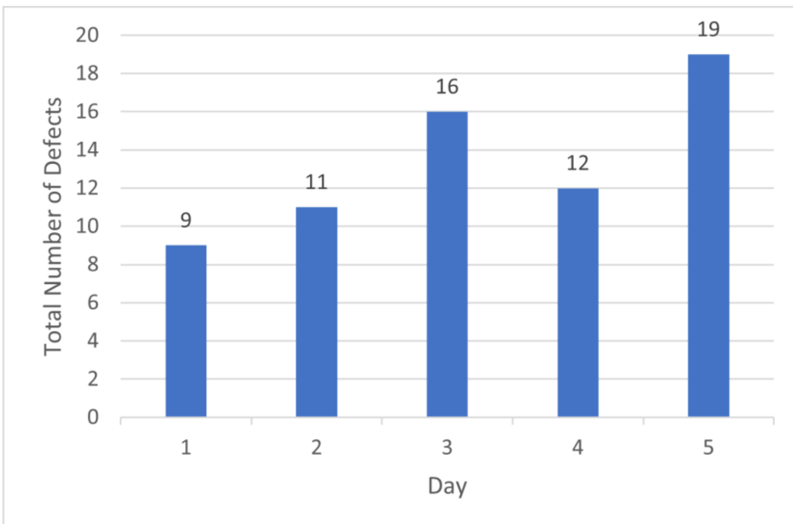

Figure 4. Defects per day

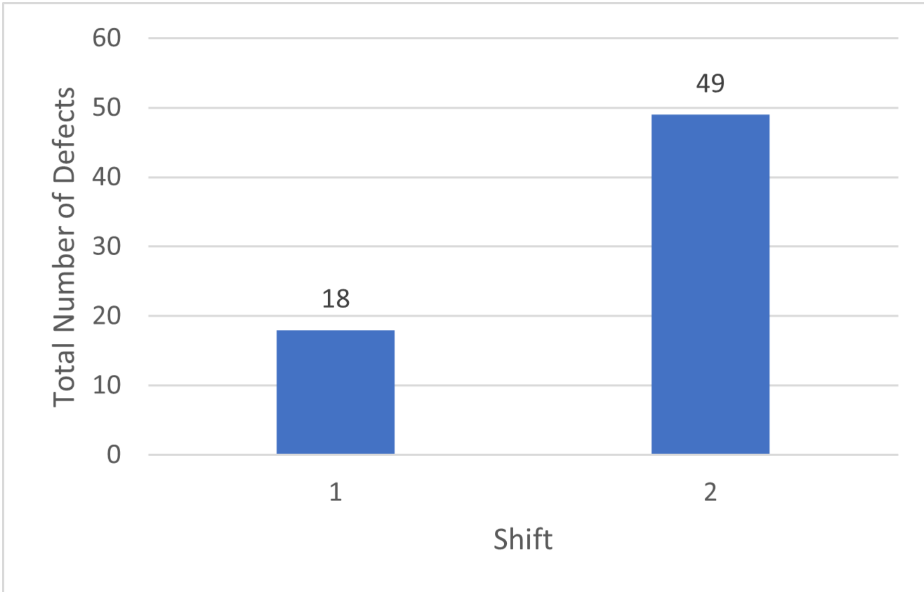

Figure 5: Defects per shift

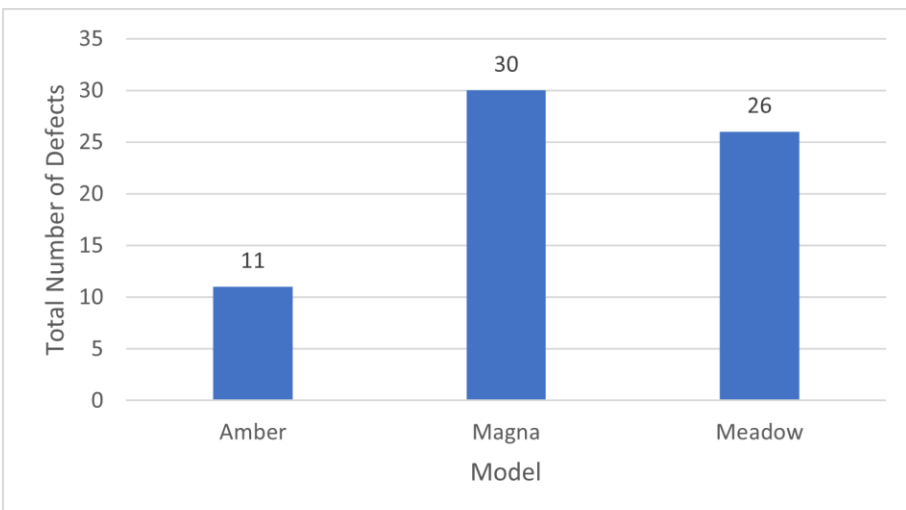

Figure 6: Defects per model

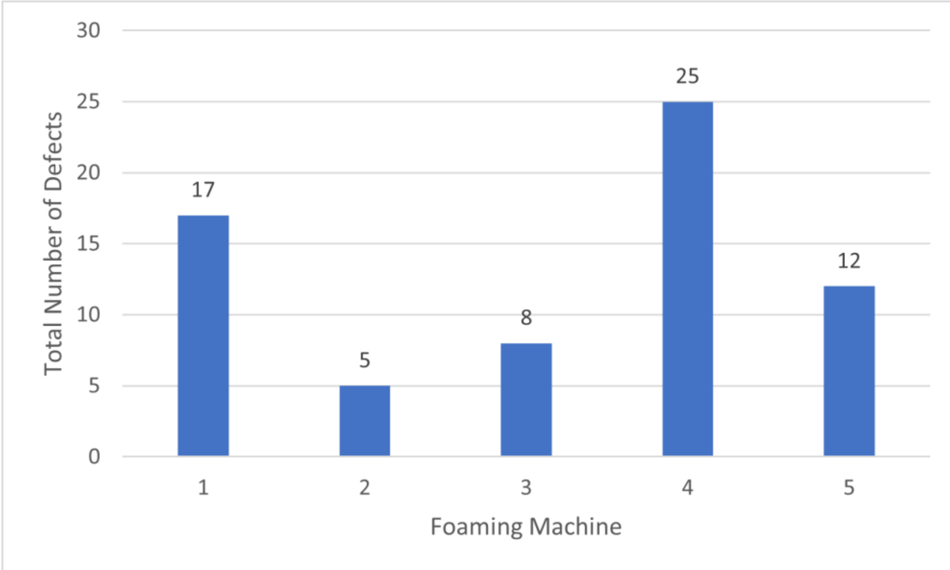

Figure 7: Defects per foaming machine

2. Construct and analyze the appropriate quality control charts for each day, first with specified mean and limits, and then with the calculated mean and control limits. What conclusions can you draw from this analysis?

More cabinets are within the upper control limit with the specified limits as more foam will provide better insulation and avoid condensation. The cabinets outside the lower control limits indicate that a considerable number of cabinets have issues. However, some of the cabinets under control using the LCL seem to be out of control using LSL. This might indicate that the process itself has a substantial variation that consistently achieving the LSL is challenging.

From the control charts for Day 1, 2, 3, and 4 (Figures 8-11), it appears that shift 2 (i.e., the second half of the data in each day) leads to more problems in the foaming process than shift 1. Day 5 seems to have an equal number of points in shift 1 and 2 outside the limits.

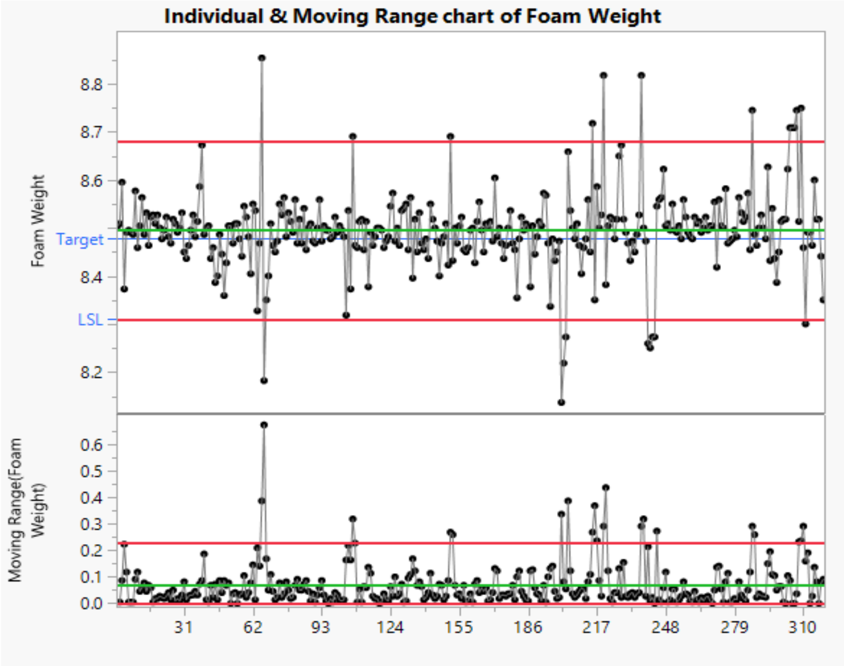

Figure 8: Day 1 control chart

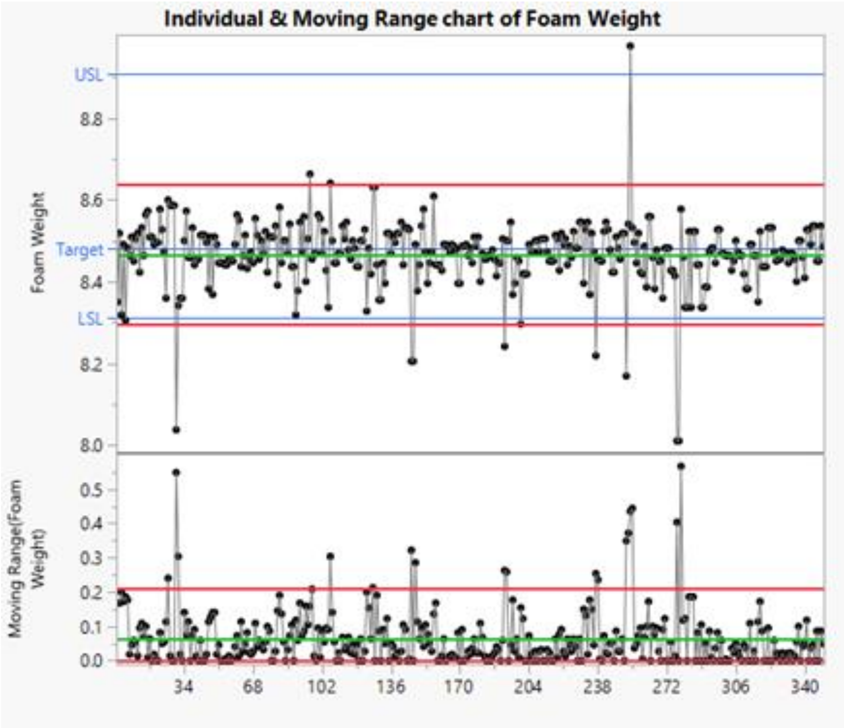

Figure 9: Day 2 control chart

Figure 10: Day 3 control chart

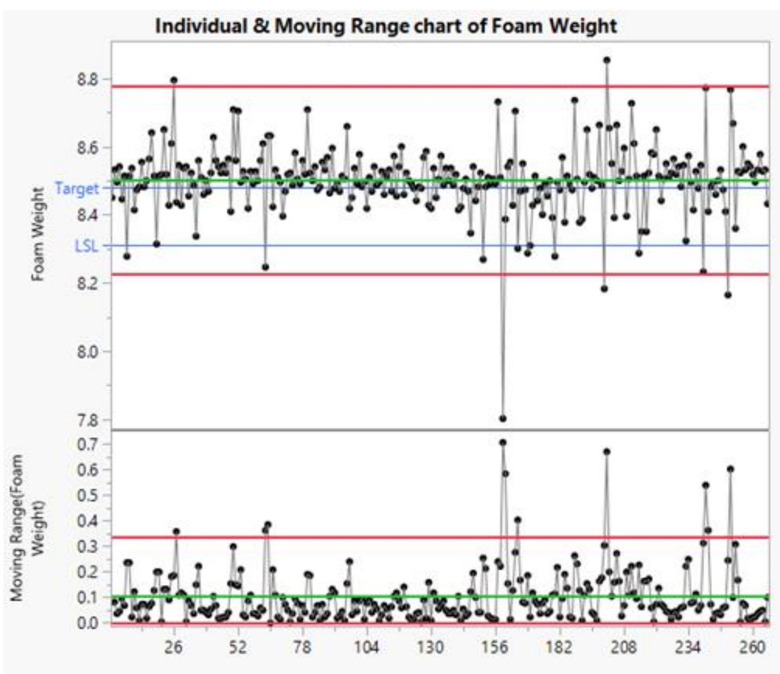

Figure 11: Day 4 control chart

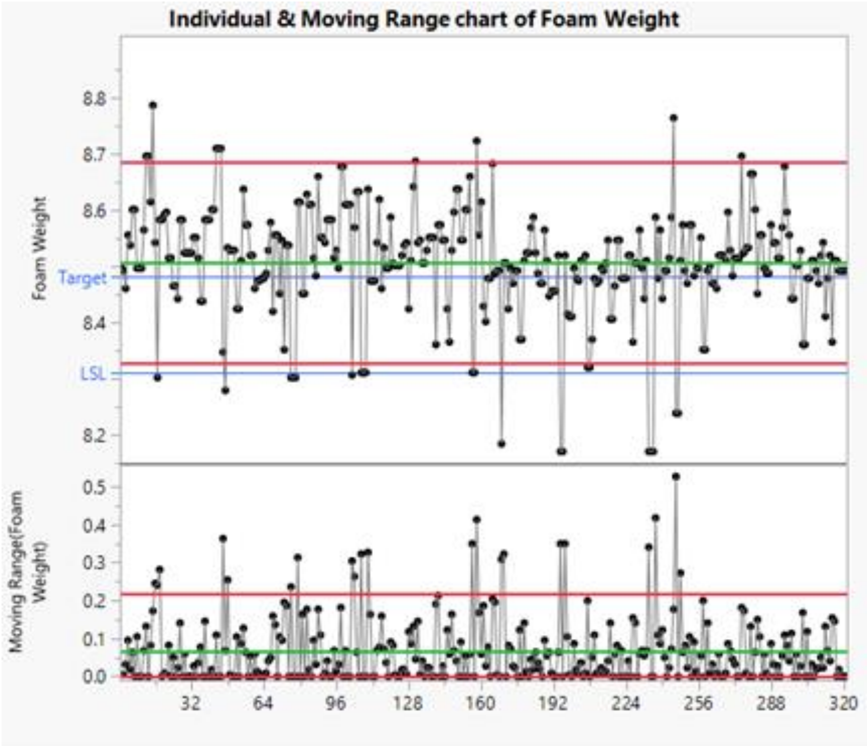

Figure 12: Day 5 control chart

3. From your analysis of the foam weight, is the process in control?

The process does not look in control as there is variation in the process, and a considerable number of cabinets lie near the control limits even if they are inside the control limits.

We also see variations between consecutive data points for all weekdays, indicating an unstable process. The variables must be evaluated for further assessment as multiple factors could be contributing to producing defects.

4. Carry out a multi-factor ANOVA for the foam weights. What factors contribute to the variation in foam weights?

It appears that the main effects and their two-way interaction impact the cabinets. The significant main effects are model, foaming machine, foam machine temperature indicating that the mean for all the models and foaming machines is different. The main-effect variables like shift and foaming machine pressure appear to be not affecting the foaming process. The significant two-way interactions are between model and shift, model and foaming machine, model, and foaming machine temperature. The interactions that are not significant to the process are between model and foam machine pressure, shift and foam machine pressure, shift and foam machine temperature, foam machine and foam machine pressure, foam machine and foam machine temperature, foam machine pressure and foam machine temperature.

A second ANOVA is performed with the significant main effects and two-way interactions from the first test. If the main effect is significant in a two-way interaction, the main effect is included in the ANOVA model even if the main effect is not statistically significant on its own. The results from the second ANOVA indicate that the main effect variables model and foaming machine and foaming machine temperature are still significant. The two-way interaction remains significant between model and shift, model and foaming machine, model, and foaming machine temperature in the second ANOVA.

The results indicate that some of the independent variables do not have significance as main effects but are significant when interacting with the other independent variables.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.090603	0.208008	43.70	<.0001*
Model[Amber]	-0.018624	0.003613	-5.15	<.0001*
Model[Magna]	-0.00019	0.003304	-0.06	0.9541
Shift[1]	0.0020236	0.002504	0.81	0.4191
Foam Machine[1]	-0.004685	0.005083	-0.92	0.3568
Foam Machine[2]	-0.000934	0.004699	-0.20	0.8425
Foam Machine[3]	0.0143632	0.004841	2.97	0.0031*
Foam Machine[4]	-0.007451	0.004675	-1.59	0.1112
FM Pressure	-5.247e-5	5.756e-5	-0.91	0.3621
FM Temp	-0.007323	0.0021	-3.49	0.0005*
Model[Amber]*Shift[1]	0.0085041	0.003571	2.38	0.0174*
Model[Magna]*Shift[1]	-0.011003	0.003289	-3.35	0.0008*
Model[Amber]*Foam Machine[1]	-0.001253	0.007911	-0.16	0.8742
Model[Amber]*Foam Machine[2]	0.0066286	0.006702	0.99	0.3228
Model[Amber]*Foam Machine[3]	-0.013214	0.00705	-1.87	0.0611
Model[Amber]*Foam Machine[4]	0.0194217	0.006819	2.85	0.0045*
Model[Magna]*Foam Machine[1]	-0.004293	0.006681	-0.64	0.5206
Model[Magna]*Foam Machine[2]	-0.01081	0.006489	-1.67	0.0959
Model[Magna]*Foam Machine[3]	0.0070253	0.006501	1.08	0.2801
Model[Magna]*Foam Machine[4]	0.0105555	0.006251	1.69	0.0915
Model[Amber]*(FM Pressure-1921.35)	8.2646e-5	7.49e-5	1.10	0.2700
Model[Magna]*(FM Pressure-1921.35)	-0.000121	7.068e-5	-1.71	0.0875
Model[Amber]*(FM Temp-68.719)	-0.006002	0.002559	-2.35	0.0191*
Model[Magna]*(FM Temp-68.719)	0.0011628	0.002133	0.55	0.5857
Shift[1]*Foam Machine[1]	0.0001665	0.005248	0.03	0.9747
Shift[1]*Foam Machine[2]	-0.001453	0.004784	-0.30	0.7614
Shift[1]*Foam Machine[3]	0.0023419	0.004886	0.48	0.6318
Shift[1]*Foam Machine[4]	0.0004392	0.004748	0.09	0.9263
Shift[1]*(FM Pressure-1921.35)	-6.818e-5	0.000053	-1.29	0.1988
Shift[1]*(FM Temp-68.719)	0.001622	0.001586	1.02	0.3065
Foam Machine[1]*(FM Pressure-1921.35)	-5.259e-5	0.000127	-0.41	0.6790
Foam Machine[2]*(FM Pressure-1921.35)	1.8458e-5	9.437e-5	0.20	0.8450
Foam Machine[3]*(FM Pressure-1921.35)	7.8422e-5	0.000104	0.75	0.4526
Foam Machine[4]*(FM Pressure-1921.35)	0.0001492	9.926e-5	1.50	0.1330
Foam Machine[1]*(FM Temp-68.719)	-0.00087	0.003389	-0.26	0.7974
Foam Machine[2]*(FM Temp-68.719)	0.0043981	0.003177	1.38	0.1664
Foam Machine[3]*(FM Temp-68.719)	-0.006792	0.003466	-1.96	0.0502
Foam Machine[4]*(FM Temp-68.719)	0.0020857	0.002907	0.72	0.4731
(FM Pressure-1921.35)*(FM Temp-68.719)	-3.938e-5	6.541e-5	-0.60	0.5473

Figure 13: Multi-factor ANOVA for all variables

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.9317134	0.114881	77.75	<.0001*
Model[Amber]	-0.018304	0.003554	-5.15	<.0001*
Model[Magna]	-0.000271	0.003269	-0.08	0.9340
Foam Machine[1]	-0.005387	0.004991	-1.08	0.2807
Foam Machine[2]	-0.001827	0.004674	-0.39	0.6959
Foam Machine[3]	0.015346	0.004751	3.23	0.0013*
Foam Machine[4]	-0.007818	0.004597	-1.70	0.0892
FM Temp	-0.006461	0.001672	-3.86	0.0001*
Shift[1]	0.0013325	0.002478	0.54	0.5908
Model[Amber]*Shift[1]	0.008659	0.003535	2.45	0.0144*
Model[Magna]*Shift[1]	-0.010802	0.003259	-3.31	0.0009*
Model[Amber]*Foam Machine[1]	-0.000611	0.007421	-0.08	0.9344
Model[Amber]*Foam Machine[2]	0.0065614	0.006564	1.00	0.3177
Model[Amber]*Foam Machine[3]	-0.013032	0.006775	-1.92	0.0546
Model[Amber]*Foam Machine[4]	0.0186495	0.006556	2.84	0.0045*
Model[Magna]*Foam Machine[1]	-0.00463	0.006613	-0.70	0.4839
Model[Magna]*Foam Machine[2]	-0.009518	0.006416	-1.48	0.1382
Model[Magna]*Foam Machine[3]	0.0069293	0.006418	1.08	0.2804
Model[Magna]*Foam Machine[4]	0.0094819	0.006089	1.56	0.1196
Model[Amber]*(FM Temp-68.719)	-0.006578	0.002493	-2.64	0.0084*
Model[Magna]*(FM Temp-68.719)	0.0024184	0.002045	1.18	0.2373

Figure 14: Multi-factor ANOVA for significant variables

5. What recommendations would you make to the team to address the issues?
    a. The primary focus must be to go through in-control and capable processes. For example, baselining the machines on the best estimate of the target volume and run the machines without tweaking the controls. The management can also eliminate or add new foaming machines. The processes related to foaming machine 4 must also be investigated.
    b. Work to eliminate special or abnormal variations and discover the common or natural variation in the process.
    c. Teach operators process control analysis so that operator has ownership of the processes to produce quality cabinets.
    d. The management must also investigate processes related to model Amber.

e. The process control charts showed that shift 2 had many defective cabinets, but it looks like both the shifts have issues. The result is a lack of operations discipline, both operators and engineering teams, making ad hoc decisions about setting the machines' controls. These ad hoc adjustments may or may not have impacted the processes but have extended the quality control making the overall processes expensive.

Table 5 provides answers to assess the performance of students. Best answer column provides solutions that explains all the points asked in the questions. Satisfactory answer column provides solutions where some parts of the question are answered. Unsatisfactory answer column provides solutions where no parts of the question are answered.

Table 5: Rubrics for answers part B

Question	**Best answer**	**Satisfactory answer**	**Unsatisfactory answer**
1	Pivot tables and bar charts for finding most number of defects for each variable Recognizing that this type of analysis is only looking at one factor at a time	Using bar charts without interpreting their meaning	Failure to identify which day, shift, model, and foaming machine lead to the greatest number of defects
2	Construct control charts with specification limits and control limits Impact of using the specification limits and control limits	Constructing charts using only one type of limits	Confusing mean of specification limits for control limits
3	Recognizing that the process is out of control Variation among consecutive points	Process may be out of control Problems in second shift	Claiming that the process is in control

4	Multi-factor ANOVA using factors affecting foam weight Second run of ANOVA using the significant variables and two-way interactions from first run Select right type for variable before running	First run of ANOVA using factors affecting foam weight Identifying whether a variable is nominal, ordinal, or continuous	Not selecting right type for variable before running Considering all variables as factors affecting foam weight
5	Add/ eliminate foaming machines Avoid dependance on inspection Investigate processes related to significant variables	Avoid variation in process by training operators process control Investigate model Amber	Eliminate inspection Constantly tweak foaming machines

CHAPTER 4: CONCLUSION

The case presented real-world situations demonstrating the complexity and unpredictability of the real issues in a manufacturing environment. The case study highlighted the need for a multi-disciplinary approach to problem-solving; in our case, part A focused on a qualitative approach, and part B focused on a qualitative approach. A multi-disciplinary approach also leads us to understand that often there are no perfect solutions to given problems and gets students to think about solutions rather than just focusing on the problems.

This case study was presented in the IE 561 Total Quality Management course in Fall 2020. The teaching was divided into two parts, Part A focusing on qualitative analysis in the first class and Part B focusing on quantitative analysis in the second class. When discussing Part A, students recognized that organizational problems at CoolKast contribute to quality problems. A good discussion revolved around that these refrigerators are premium models and yet CoolKast seems to be penny pinching when it comes to having good equipment to produce these refrigerators (i.e., the foaming machines). The students quickly identified several of Dr. Deming's points that apply to this situation. Teaching part B focused on explaining how pivot tables and the software JMP could help them analyze the data and run ANOVA tests.

Overall, presenting the case study to students was a good engaging experience, and the basic idea of the case study was well received among the students and the course instructor.